

OPEN CLUSTERS AS LABORATORIES:

THE ANGULAR MOMENTUM EVOLUTION OF YOUNG STARS

Grant NAGW-2698

Annual Status Report No. 3

For the period 1 May 1994 through 30 April 1995

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This is the annual status report for the fourth year of our LTSA grant "Open Clusters as Laboratories." Much of our time during the past year was devoted to completing the analysis of our ROSAT PSPC observations of nearby open clusters and submitting papers to the *Astrophysical Journal* and the *Astronomical Journal* describing our results. We continued at a reduced level of effort observations of open clusters with the HRI instrument on ROSAT where those observations can provide useful constraints on specific stars – these observations have mostly not yet been conducted, so their analysis will be part of our Year 5 effort. During the past year, we submitted proposals in response to the ISO open time AO (in order to carry out the circumstellar disk portion of our LTSA project, postponed due to the ISO launch delay); we recently learned that both of our circumstellar-disks-in-open-clusters proposals were approved (and with nearly all the time we asked for in Category 1 and 2), so we now look forward to eventually completing that part of our program. (Stauffer is also Co-Investigator on two approved ISO programs aimed at searches for brown dwarfs in nearby open clusters.)

Our group has obtained ROSAT PSPC observations of the following open clusters: IC2602 (age=30Myr); Alpha Persei (age=50Myr); Pleiades (age=70Myr); NGC6475 (age=200Myr); Hyades (age=600Myr); and Praesepe (age=600Myr). In addition we obtained ROSAT HRI observations of the Trapezium cluster (age=1Myr). HRI observations of IC4665 and NGC2232 are scheduled in March/April of this year. Papers describing the IC2602, NGC6475, and Alpha Persei results have recently been submitted to journals; papers on the other clusters have already been published. This represents by far the great majority of what has been published on the ROSAT observations of coronal activity for stars in nearby open clusters. In these papers, we show a clear evolution in the coronal luminosities/temperatures of young low mass stars which is a function of stellar mass and rotational velocity. It is possible to explain the time evolution of coronal properties of low mass stars in these clusters with a knowledge of how the rotational velocity distribution (as a function of mass) varies with time and with a simple model of the dependence of L_X on rotational velocity. The strength of our group is that we have both the x-ray expertise to conduct the ROSAT analysis and the optical expertise to obtain and analyze the optical data to derive rotational velocities for the stars in these clusters.

For the younger clusters in our sample, we examined the time series x-ray data to search for flares and for longer term coronal variability. Two papers were submitted identifying flare stars we found in the Pleiades and Trapezium clusters and providing physical parameters for those flares. Evidence for long term variability is surprisingly negative – for example, in the Pleiades and Hyades most stars appear not to vary by more than a factor of two over timescales of months or years. This is in contrast to the Sun, and presumably other relatively inactive stars, where there is more than a factor of ten variation in x-ray luminosity over long (decade) timescales.

We continued various activities related to our HST WF/PC observations of the Trapezium cluster. Two papers were published during the past year: one that estimated the fraction of Trapezium cluster members with protoplanetary circumstellar disks and provided PC images of two of the bow-shock features which are believed to be the interaction between these disks and the O star winds; and a second that provided near-infrared photometry for the Trapezium cluster members. A final paper providing spectral types and reddening estimates and using those data to estimate the stellar mass function for the Trapezium cluster is in progress.

During the past year, we pursued a very vigorous program to obtain rotational velocities for the low mass stars in the clusters we observed with ROSAT. Members of our group were assigned ~20 nights of time on large telescopes (MMT, KPNO and CTIO 4m, Keck) to obtain echelle spectra in order to determine spectroscopic rotational velocities in IC2391, IC2602, Alpha Persei, NGC6475, and the Hyades – vsini's were determined for >150 low mass stars in these clusters. We also were assigned >60 nights of time on small telescopes to obtain photometric rotational periods for the slowly rotating members of these clusters – we expect this to provide rotational periods for >40 stars once we complete analysis of these data.

As a backup project for our CTIO 4m echelle observing run, we obtained high resolution spectra of the M dwarf companion to HR4796A, an A0 star with a large IR excess from a circumstellar disk (i.e., a β Pic analog). Based on the very strong lithium absorption line and its position in an HR diagram, we estimate that the M dwarf companion has an age of about 10Myr – which is presumably also the age for the A0 primary. Thus, at least for HR4796B, the explanation for the large IR excess is that we are just seeing perhaps a slightly older version of a Herbig Ae/Be star, and that the star is unusual primarily just because it is young. The usual explanation for β Pic has been that it is an A star of average age (a few hundred Myr) exhibiting a rare malady (a relatively long-lived disk); our observations for HR4796 may suggest that these stars could instead just be very young A stars going through a normal, but very brief, stage of their evolution.

MacGregor continued development of theoretical models of the angular momentum evolution of low mass stars. The latest version of the models incorporates disk-regulated PMS rotation – a newly predicted facet of the evolution of these stars that may provide the key to interpreting the distribution of rotational velocities and x-ray emission for stars in our young open clusters.

We held one team meeting during this period, which was attended by representatives from OSU, SUNY, Wesleyan U., Gettysburg U., and Yale as well as by the LTSA team members. The next team meeting will be in August 1995.

Papers published or submitted for publication during this performance period:

Additional Constraints on Circumstellar Disks in the Trapezium – J. Stauffer, L. Hartmann, C. Prosser, and M. McCaughrean, 1994, *AJ* 108, 1375.

A CCD-Based Search for Very Low Mass Members of the Pleiades Cluster – J. Stauffer, D. Hamilton, and R. Probst, 1994, *AJ* 108, 155.

Coronal X-Ray Sources in the Hyades: A 40 ksec ROSAT Pointing – R. Stern, J. Schmitt, J. Pye, S. Hodgkin, J. Stauffer, and T. Simon, 1994, *ApJ* 427, 808.

A Deep Imaging Survey of the Pleiades with ROSAT – J. Stauffer, J.-P. Caillault, M. Gagné, C. Prosser, and L. Hartmann, 1994, *ApJS* 91, 625.

Deep ROSAT HRI Observations of the Orion Nebula Region – M. Gagné, J.-P. Caillault, and J. Stauffer, May 1995, *ApJ*.

The Evolution of the Lithium Abundances of Solar-Type Stars. V. K Dwarfs in the Hyades – D. Soderblom, B.F. Jones, J. Stauffer, and B. Chaboyer, 1995, *AJ* submitted.

High Resolution Infrared Imaging of the Trapezium Cluster: A Stellar Census – M. McCaughrean and J. Stauffer, 1994, *AJ* 108, 1382.

Radial Velocities of Very Low Mass Stars and Candidate Brown Dwarf Members of the Pleiades and Hyades – J. Stauffer, M. Giampapa, J. Liebert, and D. Hamilton, 1994, *AJ* 108, 160.

Radial Velocities of Very Low Mass Stars and Candidate Brown Dwarf Members of the Hyades and Pleiades: II. – J. Stauffer, J. Liebert, and M. Giampapa, 1995, *AJ* 109, 298.

A Radial Velocity Survey of the Open Cluster IC4665 – C. Prosser and M. Giampapa, 1994, *AJ* 108, 964.

ROSAT All-Sky Survey Observations of the Hyades Cluster – J.H.M.M. Schmitt, R. Stern, and P. Kahabka, 1995, *ApJ* in press.

ROSAT HRI Observations of Hot Stars in the Orion Nebula – J.-P. Caillault, M. Gagné, and J. Stauffer, 1994, *ApJ* 432, 386.

ROSAT X-Ray Luminosity Functions of the Hyades dK and dM Stars – J. Pye, S. Hodgkin, R. Stern, and J. Stauffer, 1994, *MNRAS* 266, 798.

Rotation Periods of Open Cluster Stars III – C. Prosser, M. Shetrone, S. Williams, D. Backman, B. Laaksonen, L. Marschall, and J. Stauffer, March 1995, *PASP*.

Spectral and Temporal Characteristics of X-Ray Bright Stars in the Pleiades – M. Gagné, J.P. Caillault, and J. Stauffer, 1995, *ApJ* accepted.

The Stellar Mass Function of Praesepe – D. Williams, G. Rieke, and J. Stauffer, 1994, *ApJ* submitted.

The X-Ray Properties of the Young Open Cluster IC 2602 – S. Randich, J. Schmitt, C. Prosser, and J. Stauffer, 1994, *AA* accepted.

The X-Ray Properties of the Young Open Cluster around Alpha Persei – S. Randich, J. Schmitt, C. Prosser, and J. Stauffer, 1995, *AA* accepted.

An X-Ray Survey of the Open Cluster NGC6475 (M7) with ROSAT – C. Prosser, J. Stauffer, J.-P. Caillault, S. Balachandran, R. Stern, and S. Randich, 1995, *AJ* submitted.

